Spruce and Peatland Responses Under Climatic and Environmental Change

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An experiment to assess the response of northern peatland ecosystems to increases in temperature and exposures to elevated atmospheric CO_2 concentrations

Peatlands cover only 3% of Earth's land surface but contain about 20% of the global soil carbon pool. Peat deposits originated from woody plants and moss-generated litter. Because of cold, oxygen-poor conditions, the carbon contained in northern peatlands has accumulated for thousands of years. Under current warming trends and consistent with climate projections, such accumlations of carbon are now viewed as being vulnerable to further decomposition or mineralization. If global temperatures warm as projected at higher latitudes, these peatlands could release large amounts of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) that could accelerate global warming. Our ability to predict or simulate the fate of the stored carbon in response to climatic disruption remains hampered by a limited understanding of the controls of carbon turnover and the composition and functioning of peatland ecosystems.

To identify and quantify these critical environmental response mechanisms, the Terrestrial Ecosystem Science (TES) program within the Department of Energy's (DOE) Office of Biological and Environmental Research (BER) is supporting a whole-ecosystem experiment in an ombrotrophic bog (i.e., a raised bog that receives all water and nutrients from direct precipitation) located in the Marcell Experimental Forest of northern Minnesota. The Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE) project, led by Oak Ridge National Laboratory (ORNL), will enable the assessment of ecological responses across multiple spatial scales—including microbial communities, bryophyte populations, various higher plant types, and some animal groups. The experiment will evaluate a wide range of increased temperatures and levels of elevated atmospheric CO_2 concentrations. Direct and indirect effects of the experimental perturbations will be tracked and analyzed over a decade. This comprehensive suite of spruce-peatland process studies and observations is being strongly linked to model development and application requirements for improving process representation, calibrating models, and evaluating model predictions for boreal systems. SPRUCE is a cooperative joint venture among scientists from DOE national laboratories, the U.S. Department of Agriculture (USDA) Forest Service, and universities.

Aerial View of SPRUCE Project Setting. *SPRUCE research is being conducted on an 8.1 hectare peatland of the Marcell Experimental Forest in northern Minnesota. The remote landscape includes a mix of uplands, bogs, fens, lakes, and streams.*

Key SPRUCE Science Questions

The experiment's overarching science questions cover ecosystem responses ranging from the microbe to landscape scale. They include:

- How vulnerable are peatland ecosystems and organisms to climatic change?
- Will changes in physiology under elevated CO_2 impact a species' sensitivity to warming or its competitive capacity?
- Will deep belowground warming release unexpected amounts of greenhouse gases and solutes from carbon buried for thousands of years?
- What are the critical air and soil temperature response functions for ecosystem processes and their constituent organisms?
- Will ecosystem services (e.g., biogeochemical, hydrological, or societal) be compromised or enhanced by climatic change?

Answers to these questions will provide insights not only for small-scale processes but also for landscape-relevant water, carbon, and energy fluxes for similar peatlands. Results will inform higher-order models of vegetation responses under various levels of climatic warming and associated end-of-century atmospheric change.

Warming and CO_2 Treatments

By 2100, future terrestrial environments are projected to be 4° C to 8° C warmer than today, depending on the latitude. Mean deep soil (> 1 m) temperatures also will rise with climate warming. A series of large, open-topped aboveground enclosures and a new method for warming soils from the surface down to approximately 2 m are being installed in the bog to simulate various levels of warming and CO_2 exposure at the whole-ecosystem scale. Soil and air temperatures within these chambers will cover multiple levels of warming from

Whole-Ecosystem Warming Method. *Experimental chambers are being built to provide warming from the tree tops to the deep soil (-2 m to -3 m). The open-topped chambers encompass 12-m diameter internal study areas, with 8-m tall side walls. A subsurface corral isolates the belowground peat environment for measures of local hydrologic conditions. Left: Inside a prototype chamber. Right: Installation site with boardwalk access.*

ambient to +9° C. Simultaneously, atmospheric CO_2 levels within the enclosures will be elevated up to 800 to 900 parts per million to reflect current expectations for the levels that may be associated with end-of-century temperatures.

This new experimental system provides a platform for testing the mechanisms controlling the vulnerability of organisms, biogeochemical processes, and ecosystem functions to important environmental change variables (e.g., thresholds of organisms to decline or mortality, limitations to regeneration, biogeochemical limitations to productivity, and the cycling and release of CO_2 and CH_4 to the atmosphere). The ultimate goal is to determine the levels of warming at which ecosystems will reach a critical change in temperature and CO_2 levels in the future that would push them into a new state (i.e., altered community composition and capacity to store carbon).

Connecting Observations to Models for Improved Climate Predictions

New modeling approaches are needed to incorporate the complex relationships between warming, drying, mineralization processes, and vegetation responses associated with climatic change. The experimental data generated by SPRUCE will provide quantitative evidence of the effects of climate forcing by temperature and elevated CO_2 on northern peatland ecosystems and the vast carbon stores associated with the hydrology and biogeochemistry of these globally widespread landscapes. These data can lead to key improvements in how biogeochemistry models (and further community models) represent the temperature dependence of carbon losses as CO_2 and CH_4 and the extent to which they might be counterbalanced by enhanced net primary production that is driven by a longer growing season, nutrient enrichment, and elevated atmospheric CO_2 levels.

Research Platform for the Scientific Community

The core suite of SPRUCE research is being pursued by scientists at ORNL and the USDA's Forest Service. Collaborations with universities have been established to leverage the project, and more are encouraged. Also welcomed are new initiatives consistent with the design, science mission, spatial constraints, and integrity of the experiment on the sensitive bog ecosystem. Collaboration opportunities include:

- Canopy albedo changes
- Remote sensing of canopy function
- Microscale LIDAR
- Bole respiration
- Biogeochemical cycling of trace elements
- Trace gas emissions
- Mycorrhizal studies
- Nitrogen fixation
- Herbivory
- Arthropod populations
- Amphibian and reptile populations
- Food web linkages
- Lichen productivity and decomposition
- Pests and pathogens (host defenses vs. pathogen virulence)

For more information on how to become involved with the SPRUCE project, go to **mnspruce.ornl.gov/contact.**

Bog Elevation Measurements. *These measurements are being collected as a reference for potential warming-induced change.*

***Picea-Sphagnum* Bog.** Picea mariana*, or black spruce, and* Sphagnum*, a genus of peat mosses, are the dominant overstory and groundcover, respectively, of the boreal peatland where SPRUCE is being conducted. The bog contains deep peat deposits perched several meters above the regional groundwater table.*

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